UNIVERSITI TEKNIKAL MALAYSIA MELAKA

THE EFFECT OF LEAD/GRAPHITE ON AIRCRAFT GRADE ALUMINUM ALLOY METAL SURFACE

Thesis submitted in accordance with the partial requirements of the University Teknikal Malaysia Melaka for the Bachelor of Manufacturing Engineering (Engineering Material)

By

MOHD KHUSYAIRI AZWAN BIN MOHD SHAFIEE

Faculty Manufacturing Engineering

March 2008

DECLARATION

I hereby, declared this thesis entitled "The Effect of Lead/Graphite on Aircraft Grade Aluminum Alloy Metal Surface" is the results of my own research except as cited in references.

Signature	: ………………………….
Author's Name	: MOHD KHUSYAIRI AZWAN B. SHAFIEE
Date	: 25 MARCH 2008

APPROVAL

This PSM submitted to the senate of UteM and has been as partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Material Engineering). The members of the supervisory commitee are as follows:

....

(MR. MOHD FAIRUZ BIN DIMIN)

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PSM

JUDUL:

THE EFFECT OF LEAD/GRAPHITE ON AIRCRAFT GRADE ALUMINUM ALLOY METAL SURFACE

SESI PENGAJIAN: **SEMESTER 2 (2007-2008)**

Saya **MOHD KHUSYAIRI AZWAN BIN MOHD SHAFIEE**
mengaku membenarkan laporan PSM / tesis (Sarjana/Doktor Falsafah) ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

1. Laporan PSM / tesis adalah hak milik Universiti Teknikal Malaysia Melaka dan penulis.
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja dengan izin penulis.
3. Perpustakaan dibenarkan membuat salinan laporan PSM / tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. *Sila tandakan (√)

☐	SULIT	(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia yang termaktub di dalam AKTA RAHSIA RASMI 1972)
☐	TERHAD	(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)
☐	TIDAK TERHAD	

(MOHD KHUSYAIRI AZWAN)
Alamat Tetap:
NO1, JLN CHENGAL 3/1,
TAMAN CHENGAL, 28000,
TEMERLOH PAHANG.

(MOHD FAIRUZ BIN DIMIN)

Cop Rasmi:

Tarikh: ______________________

* Jika laporan PSM ini SULIT atau TERHAD, sila lampirkan surat daripada pihak organisasi berkenaan dengan menyatakan sekali sebab dan tempoh tesis ini perlu dikelaskan sebagai SULIT atau TERHAD.

ABSTRACT

This report presents the study of the rate of pitting corrosion on Aluminum Alloy 2014-T4 sheet when in contact with different type of graphite pencil immerse in different molarity of solution. This project is divided into 2 scopes that are the project literature and the project experiment. In the project experiment an accelerated corrosion environment using apparatus in the chemistry laboratory environment using solution of Sodium Chloride is used. The samples are marked using different grade of pencil ranging from 2B to 7B. The rate of corrosion is calculated from the mass losses that have been achieved by subtracting the mass before cleaning and after cleaning process have been done. In this thesis, it also includes with, the calculation for the rate of corrosion, the EDX value for the composition of the aluminum that have been immerse and also the Scanning Electron Microscope images of the corrosion product under 1000X magnification. The result of this research has been successful and thus shows that the graphite content of the pencil do accelerate the rate of corrosion of Aluminum Alloy 2014-T4, although that some improvement need to bee done in the future.

ABSTRAK

Tesis ini menerangkan tentang kajian terhadap kadar kakisan bagi bahan aluminum alloy 2014-T4 dimana ia bersentuhan dengan pelbagai jenis pensil graphite yang direndam didalam pelbagai kepekatan larutan Sodium Chloride. Projek ini terbahagi kepada 2 skop kajian dimana skop bahagian pertama merangkumi data dan kajian ilmiah projek dan eksprimen projek di bahagian skop kedua. Di dalam menghasilkan projek ini, satu persekitaran kakisan yang di percepatkan telah dihasilkan dengan menggunakan perkakasan dan peralatan didalam makmal kimia dengan menggunakan larutan Sodium Chloride. Sampel yang digunakan di tanda dengan menggunakan pelbagai gred pensil dari 2B kepada 7B. Kadar kakisan dikira daripada kehilangan berat yang terhasil daripada penolakan berat sebelum proses pembersihan dan selepas proses pembersihan dengan menggunakan kertas pasir pelbagai gred. Di dalam tesis ini juga menyentuh kepada pengiraan kadar kakisan bagi sampel, nilai EDX bagi komposisi bahan yang terhasil selepas proses perendaman dan juga imej produk kakisan daripada Scanning Electron Microscope pada pembesaran 1000X. Secara kesimpulannya, kajian ini mendatangkan hasil yang memberangsangkan dengan ia menunjukan bahawa kandungan graphite didalam pensel mengakibatkan kadar pengkaratan meningkat ke atas Aluminum Alloy 2014-T4 walaupun terdapat sedikit perubahan perlu dilakukan pada masa hadapan.

DEDICATION

For My Family

ACKNOWLEDGEMENTS

In the name of ALLAH, the beneficent, the merciful. It is with the deepest sense of gratitude of the Almighty ALLAH who gives strength and ability to complete this project and thesis as it is today.

Firstly, I would like to express my sincere appreciation to my project supervisor for my Mr. Mohd Fairuz Bin Dimin for his support, advice and guidance of this project. I would like also to thank my parents Mohd Shafiee Bin Khamis and Norfabilah binti Mat Daham for giving me the support and courage that I needed to complete this research. Lastly I would like to thank Raihana Ramle for giving me the support and courage on completing this report.

To the technician and also to the other lecturer of Faculty Manufacturing Engineering who give commitment during the research had been made. Their advice and assistance in various ways have been extremely helpful and I would also like to say thank you to my friends and other people that are not listed here directly or indirectly in fulfilling this research. Thank You

TABLE OF CONTENTS

Abstract……………………………………………..………………………………i
Dedication…………………………………………………………...…………..iii
Acknowledgement…………………………………………………………………iv
Table of Contents…………………………………………………………………...v
List of Figures……………………….……………………………………..viii
List of Tables……………………………………………………………………....ix
List of Graph……………..…………………………………………………………x

1.0 INTRODUCTION 1

1.1 Background 1
1.2 Problem Statement 2
1.3 Objective 3
1.4 Project Scope.. 3
1.5 Gantt Chart For PSM 1.. 4
1.6 Gantt Chart For PSM 2.. 5

2.0 LITERATURE REVIEW 6

2.1 Aerospace Design.. 6
2.2 Aluminum Metallurgy.. 9

2.2.1 Heat Treatable Aluminum Alloy.. 10
2.2.2 Material Composition of Aluminum Alloy 2014-T4 13
2.2.3 Mechanical Properties of Aluminum Alloy 2014-T4...................................... 13

2.2.4 Thermal Properties of Aluminum Alloy 2014-T4 15
2.2.5 Processing Properties of Aluminum Alloy 2014-T4 16
2.2.6 Electrical and Physical Properties 16

2.3 Electromotive Force 17
2.4 Galvanic Series 17

2.4.1 Galvanic Cell 18
2.4.2 Galvanic Compatibility 20

2.5 Type of Corrosion 21
2.6 Graphite in Pencil 25
2.7 Sodium Chloride 26
2.7 Failure Case Study 27

3.0 METHODOLOGY 29

3.1 Introduction 29
3.2 Material and Equipment 30
3.3 Test Samples 30
3.4 Test Procedure 31
3.5 Examination 32
3.6 Cleaning Method 32
3.7 Extent of Pitting 33
3.8 Evaluation of Pitting 33
3.9 Corrosion Rate 34

4.0 RESULT 36

4.1 Sample Measurement Data 36
4.1 Mass Loss Evaluation 38
4.2 Rate of Corrosion 40

4.3 Scanning Electron Microscope (SEM)……………………………………….45
4.3.1 Pencil 2b……………………………………………………………...45
4.3.2 Pencil 5B……………………………………………………………..48
4.3.3 Pencil 7B……………………………………………………………..51
4.4 EDX……………………………………………………….…………….54

5.0 DISCUSSION………………………………………………………………59

5.1 Mass Loss Evaluation……………………..……………………………….59
5.2 Rate of Corrosion..…………………...……………………...……………….64
5.3 scanning electron microscope (SEM)……………...……………………………70

5.0 CONCLUSION…………………………………………………………….72

REFERENCE.. 74

LIST OF FIGURES

2.1	Standard Galvanic Cell	18
2.2	Graphite Concentration in Various Pencil Grade	25
4.1	SEM Image for Pencil 2B 0.5M under Magnification 1000X	45
4.2	SEM Image for Pencil 2B 1.0M under Magnification 1000X	45
4.3	SEM Image for Pencil 2B 1.5M under Magnification 1000X	46
4.4	SEM Image for Pencil 2B 2.0M under Magnification 1000X	46
4.5	SEM Image for Pencil 2B 2.5M under Magnification 1000X	47
4.6	SEM Image for Pencil 5B 0.5M under Magnification 1000X	48
4.7	SEM Image for Pencil 5B 1.0M under Magnification 1000X	48
4.8	SEM Image for Pencil 5B 1.5M under Magnification 1000X	49
4.9	SEM Image for Pencil 5B 2.0M under Magnification 1000X	49
4.10	SEM Image for Pencil 5B 2.5M under Magnification 1000X	50
4.11	SEM Image for Pencil 7B 0.5M under Magnification 1000X	51
4.12	SEM Image for Pencil 7B 1.0M under Magnification 1000X	51
4.13	SEM Image for Pencil 7B 1.5M under Magnification 1000X	52
4.14	SEM Image for Pencil 7B 2.0M under Magnification 1000X	52
4.15	SEM Image for Pencil 7B 2.5M under Magnification 1000X	53
4.16	Composition of Material Using Pencil 2B under EDX	54
4.17	Composition of Material Detected under EDX	55
4.18	Composition of Material Using Pencil 5B under EDX	56
4.19	Composition of Material Detected under EDX	57
4.20	Composition of Material Using Pencil 7B under EDX	57
4.21	Composition of Material Detected under EDX	58
5.1	Pitting Corrosion Appears on the Surface of the Sample	70

LIST OF TABLES

3.1 K-Constant Value 35

4.1 Weight of Aluminum Alloy 2014-T4 Marked Using 2B Pencil 37

4.2 Weight of Aluminum Alloy 2014-T4 Marked Using 5B Pencil 37

4.3 Weight of Aluminum Alloy 2014-T4 Marked Using 7B Pencil 38

4.4 Mass Loss and Density for Aluminum Alloy 2014-T4 Marked Using 2B Pencil 38

4.5 Mass Loss and Density for Aluminum Alloy 2014-T4 Marked Using 5B Pencil 39

4.6 Mass Loss and Density for Aluminum Alloy 2014-T4 Marked Using 7B Pencil 39

4.7 Rate of Corrosion for Aluminum Alloy 2014-T4 using Different Pencil Element for Marking 44

4.8 Weight Percentage and Atomic Percentage of Sample after Immersion 55

4.9 Weight Percentage and Atomic Percentage of Sample after Immersion 56

4.10 Weight Percentage and Atomic Percentage of Sample after Immersion 58

LIST OF GRAPH

5.1	Mass loss versus Concentration for pencil 2B	60
5.2	Mass loss versus Concentration for pencil 5B	61
5.3	Mass loss versus Concentration for pencil 7B	62
5.4	Mass loss versus Concentration for Different Type of Pencil	63
5.5	Corrosion Rate versus Concentration for Pencil 2B	64
5.6	Corrosion Rate versus Concentration for Pencil 5B	65
5.7	Corrosion Rate versus Concentration for Pencil 7B	66
5.8	Corrosion Rate versus Concentration for Various Type of Pencil	67
5.9	Corrosion Rate versus pH	68

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Aluminum Alloy has been in the aerospace business since the 1903 and it is the best material, which second only to steel as a major factor in the metal industry. The growth has been based on characteristic such as light weight, non-rusting properties, reasonably good strength and easy fabrication, modern metallurgical control of structure and properties, and favorable economics. Mostly, aluminum alloy comes with a wide range of properties and often used in engineering structures. Alloy systems are classified by a number system (ANSI) or by names indicating their main alloying constituents (DIN and ISO).

Selecting the right alloys for a given application entails consideration of several parameters such as strength, ductility, formability weldability, and also corrosion resistance. Aluminum is used extensively in modern aircraft due to its high strength and weight ratio. Aluminum alloy 2014-T6 is the most primary forging alloy that is being used for the landing gear and hydraulic cylinder. Mostly these materials are specialized in the aerospace technologies which have been place in transport aircraft, supersonic aircraft, helicopter, airframe component, and even light aircraft.

1.2 PROBLEM STATEMENT

The effect of graphite to the surface of the material are often been neglect by workers in this fields. Although that aluminum offers a wider range of corrosion résistance and its usage as one of the primary metals in the aerospace industries, the material also will undergo different type of corrosion by depending on the situation and the chemical properties involves. Aluminum alloy has a barrier of oxide film that is bonded strongly to the surface of the material and that if damaged, it will reform immediately in most of the environment. Basically, the barrier oxide film is only 1nm thick and it is highly effective in protecting the aluminum from corrosion.

From the Electromotive Force (EMF) series, graphite is placed above the aluminum alloy 2014 which have a difference of -1.01V. From these we can state that lead/graphite is less active than the aluminum alloy. Hence, aluminum alloy will corrode if in contact with graphite. These studies are mainly to use a standard galvanic test to see how long the corrosion rate will happen.

The project will use ASTM G 1-90 (Reapproved 1999), ASTM G 44-99 and ASTM G 46-94 to study the rate of corrosion on Aluminum Alloy sheet 2014-T4 when in contact with graphite/lead pencil. An accelerated corrosion environment consist of different concentration of Sodium Chloride (NaCl) shall be used to accelerate the corrosion process. By using galvanic cell, the rates of corrosion are studied and the microstructures of the corroded aluminum are checked either by using simple electronic microscope or even Scanning Electron Microscope (SEM). The type of corrosion involves in this studies are also going to be taken considered.

1.3 OBJECTIVE

The objective of this project is:

a) To study the rate of pitting corrosion on Aluminum Alloy 2014-T4 sheet when in contact with different type of graphite pencil immerse in different molarity of solution.

1.4 PROJECT SCOPE

The projects are divided into 2 phases as below:

a) Phases 1: Bachelor Project 1(Project Literature)
   i. Search the properties of material that are use for the experiment either mechanical properties or physical properties. The experiment only focuses on material testing type Aluminum Alloy 2014 and Graphite/lead.
   ii. To identifying the suitable type of material for the experiment
   iii. Designing the experiment methodology by referring to the ASTM G 1-90 (Reapproved 1999), ASTM G 44-99 and ASTM G 46-94

b) Phases 2: Bachelor Project 2 (Project Experiment)
   i. Developing the accelerated corrosion environment using apparatus in the chemistry laboratory environment using solution of Sodium Chloride.
   ii. Analysis for the rate of corrosion for pitting corrosion are done according to:
      i. Mass Loss Analysis
      ii. ASTM standard
   iii. The inspections are done only by using Visual Inspection, Optical Microscope and Scanning Electron Microscope instrument.

1.5 GHANTT CHART FOR PSM 1 2007

ACTIVITIES	**WEEK**													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
i. PSM Proposal: The Effect of Lead/Graphite to Aircraft Grade Aluminum Alloy ii. Gantt Chart for PSM 1														
Introduction: i. Background and Problem Statement ii. Objective and Project Scope														
Literature Review i. Aluminum Alloy Metallurgy ii. Electromotive Force (EMF) iii. Galvanic Series iv. Type of Corrosion														
Methodology i. Experiment Equipment ii. Experiment Procedure														
Submit Chapter 1: Introduction														
Submit Chapter 2: Literature Review														
Submit Chapter 3: Methodology														
Submit Chapter 1,Chapter 2, and Chapter 3														
Submit Full PSM Report and Presentation														

1.6 GHANTT CHART FOR PSM 2 2008

ACTIVITIES	WEEK												
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
i. PSM Proposal: The Effect of Lead/Graphite to Aircraft Grade Aluminum Alloy ii. Gantt Chart for PSM 2													
Sample Preparation i. Cut into 10mm X 24mm ii. Marking with Lead Pencil													
Sample Testing i. Solution preparation NaCl ii. Standard Immersion testing													
Sample Inspection i. Visual Inspection ii. Optical Microscope Inspection iii. SEM Inspection													
Sample Data i. Sample Cleaning Using Sand Paper 1250 ii. Weighting Sample Using Weight Measurement Unit of 4 decimal													
Submit Chapter 4: Result													
Submit Chapter 5: Discussion													
Submit Chapter 6: Conclusion													
Submit Chapter 4,Chapter 5, and Chapter 6													
Submit Full PSM Report													

CHAPTER 2

LITERATURE REVIEW

2.1 AEROSPACE DESIGN

The aircraft have been the most demanding application for aluminum alloys, by looking at the history of the development of the high strength alloy this also indicates the development of airframes. Duralumin is the first high-strength and heat-treatable aluminum alloy. It was first employed initially for the framework of rigid airships by Germany and the allies during the World War 1. Duralumin was an aluminum-copper-magnesium alloy which was originated in Germany and been developed in the United States as alloy 17S-T (2017-T4). It was firstly utilized primarily as sheet and plate.

One of the applications of aluminum alloy is Light Aircraft. The aircraft have airframes primarily of all aluminum semi monocoque construction however, some or rather a few light planes have tubular truss load carrying construction with fabric or aluminum skin and some use both. Aluminum skin is normally ranging from the minimum practical thickness of 0.015 in to 0.025 in. Although the requirements for the design strength are relatively low, the skin needs moderately a high yield strength and hardness to minimize the ground damage from stones, debris, mechanic's tools and general handling. Some of the primary factors involved in selecting an alloy for this type of application are corrosion resistance, cost and appearance.

Transport aircraft is also one of the main applications of aluminum alloy. The type of aluminum that are operated by commercial airlines either by corporation or executive travel, and by the military including Concorde craft are generally made from semi monocoque and sheet stringer aluminum construction. Most of the alloys that are primary utilized today are 2014-T4 and these alloys are used as for wing tension members, shear web, and ribs. For this application, fatigue performance and fracture toughness, combined with high strength, are the alloy characteristic that are most concern. Although 7075-T6 is stronger than 2014-T4 or 2014-T6, it is more sensitive to notches and has a higher fatigue-crack propagation rate. However the structure design and fabricated of 7075-T6 have some what less weight than is possible in a 2014-T4 or 2014-T6 structure for equivalent performance.

Landing gear structural parts for heavy airplanes are always produced as aluminum alloy forgings. The main cylinders are made on hydraulic presses as conventional closed-die forgings, with the parting plane at the center of the cylinder. In the past, alloy 2014-T6 was used extensively, but in the modern world of technology nowadays alloy 7079-T6 or T611 has been used. Other landing gear members, attached to the main cylinders, also are produced as aluminum forgings, including structural forgings in the fuselage and wings, which distribute the landing gear loads into other structures, and forged parts for the retracting mechanism.

High performance aircraft required by the military services are designed to be able to withstand 9g to 12g loads (9 to 12 times grater than imposed by unaccelerated flight). The maximum loads are uncommon, and on some aircraft it may be encountered. Since the common l-g stresses during most of a flight period are low, and the life of the aircraft in terms of flying hours is also generally low, high cycle fatigue is not a major problem. However, the high stresses that are occasionally may be imposed in maneuver demand consideration of the high stress fatigue characteristic of the structure material. Another characteristic of this type of aircraft is high wing loadings, which indicate thick wing skin, typically used about 0.5 in to 1.5 in at the root.

Supersonic aircraft are designed to withstand aerodynamic heating to 250°F for over 100hr (the time in service is accumulated in small increments), generally utilize the 2xxx series alloys in artificially aged tempers for skin sheet. Alloys 2024-T81 and T86 are the most extensively in use meanwhile 2014-T6 and 2024-T62 or T81 are used for extruded members. Alloys 2014-T6 and 2618-T61 are used for forged products located in heat-affected areas, for as alloy 2024 which can be forged which also can be considered for parts of this type. Alloy 2219 had limited application in engine pods as sheet, rivets, and forgings. The designers of one supersonic bomber have made extensive use of honeycomb core sandwich construction for wing panels, to achieve a stiff structure that does not buckle when stressed in compression near the yield strength of the material. The honeycomb in these sandwich panels is 5052 aluminum foil, except where fiber glass is applied to further insulate the fuel from aerodynamic heating.

Aircraft is not only dictated to airplane but also helicopter. Helicopters have critical structural requirements for rotor blades. Alloys 2014-T6, 2024-T3, and 6061-T6 in extruded or drawn hollow shapes, are utilized extensively for the main spar member. The blade skins, typically 0.020in to 0.040in thick, are primarily alclad 2024-T3 and 6061-T6. Some blades have alloy 3003-H19 or

5052-H39 honeycomb core while others depend on ribs and stringers spaced 5in to 12in apart to prevent excessive buckling or canning of the thin trailing edge skins. Adhesive bonding is the most common joining method. The cabin and fuselage structures of helicopters generally are of conventional aircraft design, utilizing formed sheet bulkheads, extruded or rolled sheet stringers, and doubled or chemically milled skins.

2.2 ALUMINUM METALLURGY

Wrought aluminum alloys which those are used for rolled sheet or shapes, forgings or extrusion, have standard alloy composition and temper designation systems. A four digit numerical system developed by the Aluminum Association has traditionally been used to identify composition and it is still used as the common language among the industry. The International Unified numbering System has adopted a five digit designation for aluminum with an A prefix. In this chapter, the only material focuses are the 2000 series aluminum alloy which then focuses only to Aluminum Alloy 2014.

The 2000 Series Aluminum Alloy has a principal alloying element of copper with minor additions of manganese and magnesium. This series of aluminum is the original heat treatable alloy group developed in the 1920's. The best known and most widely used heat treatable alloy for aircraft and aerospace is 2024. This type of aluminum can be spot and friction welded but can not be fusion welded. The aluminum has good formability in the annealed temper condition and some formability in the solution treated and aged condition, however it needs intelligent application in complex designs. This type of series has excellent fatigue properties when compared to other type of aluminum alloy, it also have excellent strength to weight ratio. A very good machinability and a poor resistance to corrosion without alclad layer or secondary chem. Film anodize or prime and paint.

Clad Aluminum or sometimes called Alclad but the design engineer specifies a clad alloy, or a specific alloy type with a very thin layer of pure aluminum roll bonded to both sides of the alloy sheet. This provides the best of both worlds the high strength of the heat treatable alloy with the superb corrosion resistance of a purer aluminum top layer. This roll bonding is a true metallurgical bond and it's strong as the aluminum itself.

2.2.1 Heat-Treatable Aluminum Alloys

Aluminum alloys are not allotropic they do not undergo a phase or structure change like steels when heating. But if the right alloying additions are present they can be heat treated by solution heat treating and precipitation hardening. In the early days of 1930's solution heat treatment was referred to as ST, and many times precipitation hardening was referred to as aging. Solution heat treatment involves temperatures very close to the melting point of the aluminum alloy, usually 200°F to 300°F below the melting point. The purpose is to provide enough thermal energy to dissolve in a solid solution when the alloy elements present. In the case of 2024, the major alloy element is copper, and by taking the part to 920°F, the copper present within the 2024 will dissolve or disperse uniformly throughout the solid aluminum part.

Without getting into the solid state physics of the metallurgical reactions, dissolution does occur but only at this high temperature. However, if the parts are slowly cooling down, the copper wants to come back out of solution. Quenching is a very rapid cooling down, using water on the order of 500°F to 600°F per second. Quenching locks in place all alloy elements that have been dissolved at the high solution heat treating temperature. Before the alloy additions can think about changing